FREQUENCY DIVISION MULTIPLEXING FOR
COAXIAL OR MICROWAVE RADIO SYSTEMS

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FIGURES 1 THROUGH 11

1. GENERAL

1.1 This Section provides REA borrowers, consulting engineers, con-
tractors and other interested parties with technical information
for use in the design and construction of REA borrowers' telephone
systems. It describes the principle and applications of frequency
division multiplexing (FDM) equipment designed to transmit signals
over coaxial or microwave radio facilities.

2. PRINCIPLES

2.1 Multiplexing is the process of combining quantities of voice
channels so that they may be sent over one common transmission
path. Demultiplexing at the receiving end should restore the original
character of each voice channel. This process is repeated in the
opposite direction of transmission to obtain two-way communications.
Time division multiplexing is another technique currently used for
multiplexing. Only FDM will be described in this Section. It is gen-
erally conceded that 4 kHz of bandwidth is sufficient to pass speech
information with acceptable fidelity including out-of-band signaling
(paragraph 3.4). If a transmission medium (such as a microwave system)
has a passband wide enough to contain many multiples of 4 kHz, then
this medium could pass many simultaneous voice channels. Since each
voice channel has the same frequency spectrum, a technique must be used
to translate each channel into its assigned slot in the wide band trans-
mission medium spectrum. Frequency division multiplexing is one tech-
nique that is used. TE&CM 901 describes the fundamentals of low density
carrier systems using FDM for paired cable.

2.2 High density FDM systems contain balanced modulators to translate
voice frequencies to amplitude modulated carrier frequencies. At
the receive end of the system a balanced demodulator translates the
incoming modulated carrier back to voice frequencies. Modulators and
demodulators are nonlinear devices that produce sum and difference
frequencies containing both voice and carrier information. As an example,

a 100 kHz carrier frequency applied to a balanced modulator will mix with voice frequency signals to produce 100 kHz plus the voice frequencies (upper sideband) and 100 kHz minus the voice frequencies (lower sideband) at its output terminals. The carrier only and voice only frequencies will be substantially suppressed at the output of a balanced modulator. Only one of the sidebands will be selected by filtering and transmitted to a distant terminal where a demodulator (exactly like a modulator) will again produce two sidebands at its output terminals. Either sideband of the demodulator output contains the original voice information. However, one sideband, the lower one, contains voice information only. This is exactly the result that is desired. That is, voice in, modulation to a higher frequency, transmission over a high frequency line, and restoration of the original voice information by demodulation at the receive terminal. This process is called single sideband suppressed carrier (SSBSC) modulation (and demodulation). Figure 1 illustrates this type of modulation and demodulation. High density FDM equipment designers use single sideband suppressed carrier modulation because it is an efficient way to use the baseband frequency spectrum of a communications system.

3. BUILDING BLOCKS OF AN FDM SYSTEM

3.1 Using the principle in paragraph 2, a multiplex system designer can assign a different carrier frequency to each voice channel. At the output of each modulator the voice information will have been translated to an assigned individual channel frequency slot. All of these channel frequencies can then be combined electrically and applied to a single wideband transmission line such as a coaxial cable or a microwave radio system. Additional stages of modulation and combining are used in high density FDM systems. Figures 2 and 3 illustrate low and high density multiplexing plans. Figure 4 shows several frequency plans.

3.2 The success of frequency division multiplexing is strongly dependent on stable carrier frequency generators at both ends of the system. Synchronizing these carrier generators is often necessary.

3.3 Precise bandpass filters with sharp cutoff points are needed to preserve the realm of each assigned channel. Information crossing into this realm from another channel would appear as an undesirable signal at the receive end of the system (see Figure 5).

3.4 Most frequency division multiplex systems are designed to carry an out-of-band signaling frequency with each voice channel. Out-of-band signaling requires additional channel filtering added in each channel to place a high degree of attenuation to voice frequencies above 3.4 kHz. A signaling frequency (usually 3.825 kHz) may be be applied to the channel just after this filter but just ahead of the channel modulator (see Figure 6). Now, both voice and signaling are contained in the assigned channel but separated from each other to

preserve their identity. At the receive multiplex terminal, filtering separates the desired information and directs it to a voice path and a signaling path. There is a growing tendency to retain the maximum voice frequency bandwidth in each channel by removing the signaling function. Signaling can still be accomplished by using inband tones (usually 2.600 kHz) or assigning a completely separate signaling channel or channels to the system. All channel signaling may then be carried over the special signaling channels by essentially the same multiplexing process described for voice signals. This process divides a single 4 kHz channel into a large number of narrow frequency slots into which discrete signaling tones are simultaneously applied.

3.5 Precisely controlled dc power applied to each module in the system must be distributed via a power bus that has an extremely low impedance. A small amount of power bus resistance will allow signal voltages to be developed that will feed into every part of the system. These signals could appear as unwanted noise in channels at the receive terminal.

3.6 Because all transmission media introduce level changes, automatic level regulation in the multiplex terminals is desirable. If the transmission medium is a broadband microwave system, its baseband levels will change slightly with time. Even coaxial cable systems containing automatic regulation circuitry to compensate for variations in line losses will vary with time. Level variations in each multiplex terminal at each major stage of demodulation may be controlled by level regulation at those stages. Supergroup and group regulation are commonly used to provide mop-up regulation for the entire system.

3.7 Complex systems should contain built in diagnostic or alarm circuitry. In high density frequency division multiplex systems power, carrier levels and carrier frequencies are constantly monitored. Variations exceeding predetermined values are recognized and forwarded to an alarm bus. The alarm system will act to light alarm lamps. This alarm signal may also be extended to a common office alarm system to light an aisle lamp and sound an audible alarm. Figure 7 illustrates the building blocks of a typical FDM multiplex system showing the rela- tionship of each item described in paragraphs 3.1 through 3.7.

4. APPLICATIONS

4.01 Frequency plans for high density FDM systems have some minor and some major differences (see Figure 4). Countries other than the USA have developed frequency plans shown in publications of the International Telephone and Telegraph Consultative Committee (CCITT). The Bell System has several plans for their systems. Another large US common carrier uses another frequency plan. All have similarities and differences. The differences are not only in the modulation steps. Pilot frequencies used for monitoring continuity and level changes vary from one plan to another. Impedances and levels at similar points in different systems are not always the same. When connecting companies propose to

engineer a wideband trunk route, the interconnection agreement should include a compatible FDM frequency plan for their respective multiplex terminals. Line levels and pilot frequencies should be stated. The initial spectrum assignments should be stated as well as the number of channels to be equipped. (The agreement must also confirm whether regulation and frequency synchronization are to be used in the system.)

4.02 A wideband facility such as a microwave system or a coaxial cable system should be recognized and treated as a line facility. While its flexibility is a great advantage, long range application considerations should be studied before allocating a portion of its baseband frequency spectrum to each central office that it serves. The effectiveness of group regulation is lost when the channels in a group are divided between two offices. Two regulating pilots cannot be used so a determination must be made as to which office will generate the regulating pilot frequency. Level changes at the office originating the pilot will automatically change the levels of all channels in that group. The gain of those channels assigned to the sharing office will be changed regardless of their need. This same line of reasoning may be used to discourage sharing (splitting) supergroups. When a supergroup is dedicated to one central office, effective supergroup level control can be maintained through supergroup regulation. Another advantage is noise reduction in the channels. The system noise in a common baseband spectrum is reduced when each end office has a dedicated portion of the baseband spectrum. Figure 8 illustrates and describes the effects of splitting supergroups and dedicating supergroups. Even the "Better Application" shown in Figure 8 is not the preferred application. This will be explained in paragraph 4.03.

and a resistive combining unit in each direction of transmission at a route junction. A second alternative would be to provide a splitting transformer and a combining transformer for lower losses than the resistive arrangements. Either the resistive or inductive arrangement will eliminate receiving both directions of traffic from other offices. They do not eliminate receiving all of the baseband at each receiving end office regardless of the spectrum actually used at each office. A third alternative is to provide a splitting filter in each direction of traffic at the junction station (see Figure 9 - preferred application). Splitting filters may be selected to direct only a portion of the baseband to each branch. The advantages are: (1) less loading of the wideband line facilities, (2) less noise received at each location from the wideband facility and (3) better system reliability. A fourth alternative would be to provide a multiplex terminal in each branch at the junction station. This arrangement provides maximum flexibility. The three branches of the junction station become trunk route terminals. Multiplex channels can be terminated at the junction or they can be patched through on a VF basis. Groups can be interconnected between terminals via group connectors. Supergroup connectors can be used as well as group connectors. Traffic occupying one portion of the wideband line facility spectrum in one route can be shifted to a different portion of the spectrum in another route by simply patching the group or supergroup connectors between the desired spectrum positions in each multiplex terminal. Multiplex terminals at route junctions permit using low density or high density wideband systems on each leg in accordance with predicted traffic requirements for each route. An example of a two terminal location is illustrated in Figure 10. This figure illustrates the points in a terminal which may be patched or wired to another terminal.

4.04 Signal level changes are caused by carrier or dc power changes in a multiplex terminal. They may also occur in the wideband line facility that interconnects multiplex terminals. Modern communications systems provide circuits having level stability that should not change more than a fraction of a decibel in a prescribed period of time. REA Form 397d, "Design Specifications for Point-to-Point Microwave Radio Systems," states: "The system shall be capable of providing circuits whose voice frequency levels do not vary more than .5 dB over a three month interval." A system consisting of two multiplex terminals, one to three links of wideband microwave or coaxial line facilities and perhaps a wire line entrance link will most likely suffer some small level variations in each part of the system. It cannot be assumed that each part of the system will change in the same direction. Nor can it be said that all of the level changes will be random. The effects of temperature changes on the inside and outside plant should be studied. The effects of power supply variations should be studied. The quantity of items in tandem making up the system should be noted. The individual specifications for each piece of major equipment should be studied. When all of these factors (variables) are considered, an engineering judgment can be made as to the necessity for automatic level regulation.

(A more precise method of reaching this decision would be to insert the known limits of each variable into a computer program and extract the probabilities that a stated end to end level change would not be exceeded for a given period of time.) An engineering decision to provide regulation must be followed by an investigation to determine the point or points in a system that will contribute the largest level changes. If the wideband line facility will be the major contributor, baseband regulation may be specified. If the end to end voice frequency level changes are estimated to slightly exceed the level stability objective, then multiplex supergroup regulation may be all that is necessary. In systems where the baseband slope changes, it is desirable to consider supergroup and group regulation in the multiplex terminals. Each system should be evaluated individually to assure meeting an end to end level stability requirement. In some applications the connecting company may insist on group and supergroup regulation.

4.05   Flanking effect is the interaction or mutual influence that may occur when bandpass filters are connected to a common bus. In an FDM system there are common busses at each step of the modulation and demodulation process. The system designer will make allowances for flanking on the basis that all channels, all groups, all supergroups, etc., are fully equipped. In an actual application only partially equipped shelves are the general rule. Therefore, special flanking networks are usually inserted in the equipment shelf adjacent to the last equipped channel, or group or supergroup unit to simulate the condition of interaction designed into the system. Each FDM multiplex manufacturer makes specific recommendations about the quantity, type and physical location of its flanking networks depending on the location of unequipped channels, groups, supergroups, etc.

4.06   Overloading is undesirable because it creates escalating amounts of noise in multiplex channels. This was mentioned briefly in the discussion about baseband bridges. When the total power of a complex signal exceeds the expected input to amplifying devices, these devices do not faithfully reproduce the input signal. Overloading will occur in high density multiplex systems for generally predictable increments of time when the system is fully loaded. By design, a practical compromise is reached between the cost of assuring no overloads and acceptance of a small amount of time when the system will be overloaded. Of course, the designer of a multiplex system must establish nominal individual channel input levels in order to proceed with the design of those parts of the system that will amplify many channels of signal information. This discussion should lead to a realization that to raise any channel input level above the design level at any point in an FDM system is to risk overload effects during a greater portion of time than the system designer anticipated. An equation used to approximate the RMS power increase caused by hundreds of voice signals passing through an amplifier is:

$$-16 + 10 \log N = dB$$

N = number of voice channels

-16 = average talker level (in dB) below test tone level (some use -15 instead of -16 in the power rise equation)

Example: A baseband amplifier designed to amplify a composite multiplex signal could be designed to receive a single tone input signal of -30 dBm. Its gain could be adjusted by applying a single mid band tone at -30 dBm and setting the output level for the desired gain. When an FDM composite signal containing 1000 voice signals is applied at its input terminals, the RMS power can be approximated by this equation:

$$-30 + (-16 + 10 \log 1000) = -16 \text{ dBm} \quad \text{(A 14 dB power rise)}$$

During some increments of time the voice signal voltages cannot be represented by an RMS power statement. One thousand voice signal voltages could (for an instant) be exactly in phase with each other. This peak voltage would surely overload a typical amplifier. Since the probability of all signal voltages being in phase is small, a compromise value of "peaking" is included in the amplifier design. Typical values are somewhere between 11 and 13 dB for large quantities of voice signals. This is in addition to the calculated RMS power rise for the design load of 1000 channels in the above example. Now consider the effect of low level continuous tones such as those used for signaling. Generally the same considerations apply as in voice loading. Remembering the level of the signaling tone as it compares to the test tone level, the previous equation is nearly the same.

Example: Assume a signaling tone is applied 20 dB below the -30 dBm test tone point to each of 1000 channels.

$$-30 + (-20 + 10 \log 1000) = -20 \text{ dBm} \quad \text{(A 10 dB power rise)}$$

While it is unusual to have all signaling tones and all voice energy simultaneously applied to a high density system, a good amplifier design could be based on this combined load. The combined power rise design for an amplifier which must carry 1000 voice plus 1000 signaling tones (at -20 dBm0) plus a peaking factor of 11 dB would be:

$$\text{(Power Rise} \perp \text{Power Rise)} + \text{Peaking Factor} = \text{Total Power Rise}$$
$$\text{Voice} \qquad \text{Sig.}$$

$$(14 \perp 10) + 11 = 26.5 \text{ dB above a -30 dBm test tone}$$

Note: " $\perp$ " is symbol for dB addition on a power summation basis.

So long as this amplifier is designed to accommodate peaking of 11 dB above -14.5 dBm, its performance will be satisfactory when 1000 voice

and 1000 signaling tones are present (except a very small increment of time described earlier). The preceeding example illustrates the importance of limiting individual tones, pilots, voice, data, music, etc., applied to the input of each channel in a high density FDM system. One signaling tone set 10 dB too high in the 1000 channel system described here is equivalent to adding 10 more signaling tones of the proper signaling tone level. An application engineer must exercise great care when designing a "party line" baseband system to ensure that no greater load will appear at a radio or multiplex input port than the design load stated by the equipment manufacturer. When the system is in operation, the maintenance personnel must guard against single tones several decibels higher than the line up levels. A 0 dBm test tone applied at a -16 dBm point can seriously overload a system carrying heavy traffic. Each high density multiplex channel has limiting circuitry to partially protect against overloading.

.4.07 Equalization as applied to FDM multiplex systems is difficult to describe because it is interrelated with signal levels and signal level regulation. It is also related to signal transit time. Beginning with equalization as applied to voice channel levels, it is the multiplex designer's responsibility to design the channel passband to be as "flat" or equalized across the voice band as is economically justified. When a voice circuit must be established by interconnecting several multiplex systems, it is apparent that the level differences across the voice band will be changed as each multiplex system is added. Assuming this voice circuit will be permanently connected through the same intermediate multiplex system, the end-to-end frequency response may be equalized to make all of the frequencies in the voice band appear at the same levels (+7 dBm level at the 4 wire demodulation point). When out-of-band signaling is not used, some multiplex systems will provide additional voice bandwidth that is several hundred hertz greater. A voice circuit made up of several of ' require less equalization at the high end of the ling with the idea that equalization is used to
make all frequencies appear at a common point at equal levels, it is reasonable to do some equalizing at each step of the FDM modulation process. There are 12 channels in a channel bank whose levels must be equalized before applying them to a group modulator. There are five group modulator outputs whose levels must be equalized before they are applied to a supergroup modulator. There are ten to twelve supergroup outputs which must be equalized before applying them to line facility amplifiers or still higher modulation steps. In the receiving terminal there is the same need to equalize each band of frequencies entering a receiving line amplifier and at each stage of the demodulation processes. Because there are so many possibilities for level changes, a system of automatic equalization called supergroup and group regulation is offered by FDM manufacturers. Regulation may be applied at the group, supergroup and perhaps mastergroup levels of a system. When regulation

is not provided, manual adjustment of levels must be performed at regular intervals to maintain equalization. The kind of equalization that deals with signal transit time is called delay equalization. When two different signal frequencies are transmitted through an FDM system, their transit times are different. Measurements of this relationship of transit time for all of the frequencies in an FDM channel could be plotted on a curve. The curve would indicate relative delay of a selected signal frequency with respect to any other signal frequency. By adding a delay equalizer, it is possible to make the transit time of selected frequencies appear to be equal. This form of equalization is most helpful when the maximum amount of data information is to be sent via an FDM channel. It is of little value when the channel is to be used for voice and slow speed data signals.

4.08   Power sources for FDM multiplex systems are usually 48 volt dc
       battery plants. This is the generally available telephone switching office battery voltage. A separate transmission system battery plant would be far better if economics would permit. Switching systems, ringing generators, etc., have an inherent ability to introduce noise on the battery bus. Peak switching equipment loads can cause the battery voltage to vary. Noise and voltage variations are undesirable power conditions for an FDM system. As a practical matter, all FDM manufacturers supply a power converter to reduce the power source voltage to the FDM system bus voltage (usually 20 volts dc). A simple high voltage dropping resistor could perform this function. However, since some systems will be operated from noisy, unstable power sources, the FDM power unit contains regulation, filtering and voltage dropping circuitry. A well designed power unit will not only deliver a "clean" regulated 20 volts dc but it will also present a "quiet" load to its battery source. This is a most critical unit in an FDM system. Failure of it or its power source represents catastrophic system failure. Redundant or standby power units are essential for reliable multiplex system performance.

4.09   Electromagnetic interference (EMI) will appear in multiplex
       channels as noise bursts or steady noise. It may not be present in all channels. Some sources of EMI are devices which produce arcing. Motor generators, ringing generators and some types of industrial lighting fixtures are examples of EMI sources. The degree of interference depends on three factors. These are: (1) the susceptibility of the multiplex equipment to EMI, (2) the physical distance from the source of EMI and (3) the noise power output of the EMI source. One of the obvious steps an equipment designer can take is to shield sensitive modules in the multiplex system. The application engineer can locate the multiplex racks as far from the power equipment as practical (minimum six feet). Arc suppression kits should be specified for all equipment such as motors and generators in which arcing occurs during normal operation. One other source of EMI is powerful radio, radar and television transmitters. Multiplex equipment racks and associated cabling may act as receiving antennas for radio signals. The application engineer must make certain that equipment shelves are bonded to the

equipment rack and each equipment rack is bonded to a satisfactory office grounding system. This effort will substantially reduce radio, radar and television signal interference picked out of the air. Particularly difficult interference problems may require special equipment shielding.

4.10 A trunk group noise approximation is very useful to the application engineer who is responsible for a system design which meets a specific trunk noise objective. Each item of equipment contributes noise. Using the manufacturer's statements about noise and noting how these sources are arranged in the system will permit an application engineer to estimate noise performance before the system is constructed. It is not necessary to be absolutely precise about each and every noise contribution in order to use this method of evaluating noise for alternate system arrangements. An example of noise approximations for the trunk groups in a proposed system is given in Figure 11. Trunk groups having equal quantities of equipment are all listed under one noise summation in this figure.

4.11 Alarms and a service channel or order wire may be extended from the radio site to the distant end of the wire line entrance link. The application engineer may treat the wire line entrance link as if it were one-half of a radio repeater configuration. When this is done, the wideband cable facility carries all signals. High pass-low pass filters are inserted into the baseband to provide alarm and service channel access at the radio site. At the multiplex site, the engineer will treat the signals as if they were being derived from a radio terminal. An alternate method of extending the alarms and service channel is to utilize 19 or 22 gauge pairs included in a composite cable placed between the radio and multiplex sites. In this type of application the radio site is treated as a terminal with respect to the location of alarm and service channel filters. These signals are extended over the 19 or 22 gauge pairs to the multiplex site. Voice frequency gain devices may be required to adapt the signal levels to the end equipments. Attenuation of voice frequencies in video and coaxial cables is small compared to 19 or 22 gauge pairs. Alarm systems most often use frequencies which are in the baseband range above the service channel (approximately 4 kHz). Equipment and line losses must be examined carefully in this frequency spectrum. Selection of frequencies which are close to the band edge of filters should be avoided unless the "skirt" characteristics of filters are known. Experience has shown that application engineers devote an inordinate amount of engineering time to special alarm and service channel arrangements. Less cost and better performance can be had by accepting as much standard wiring as is reasonable to accomplish necessary functions.
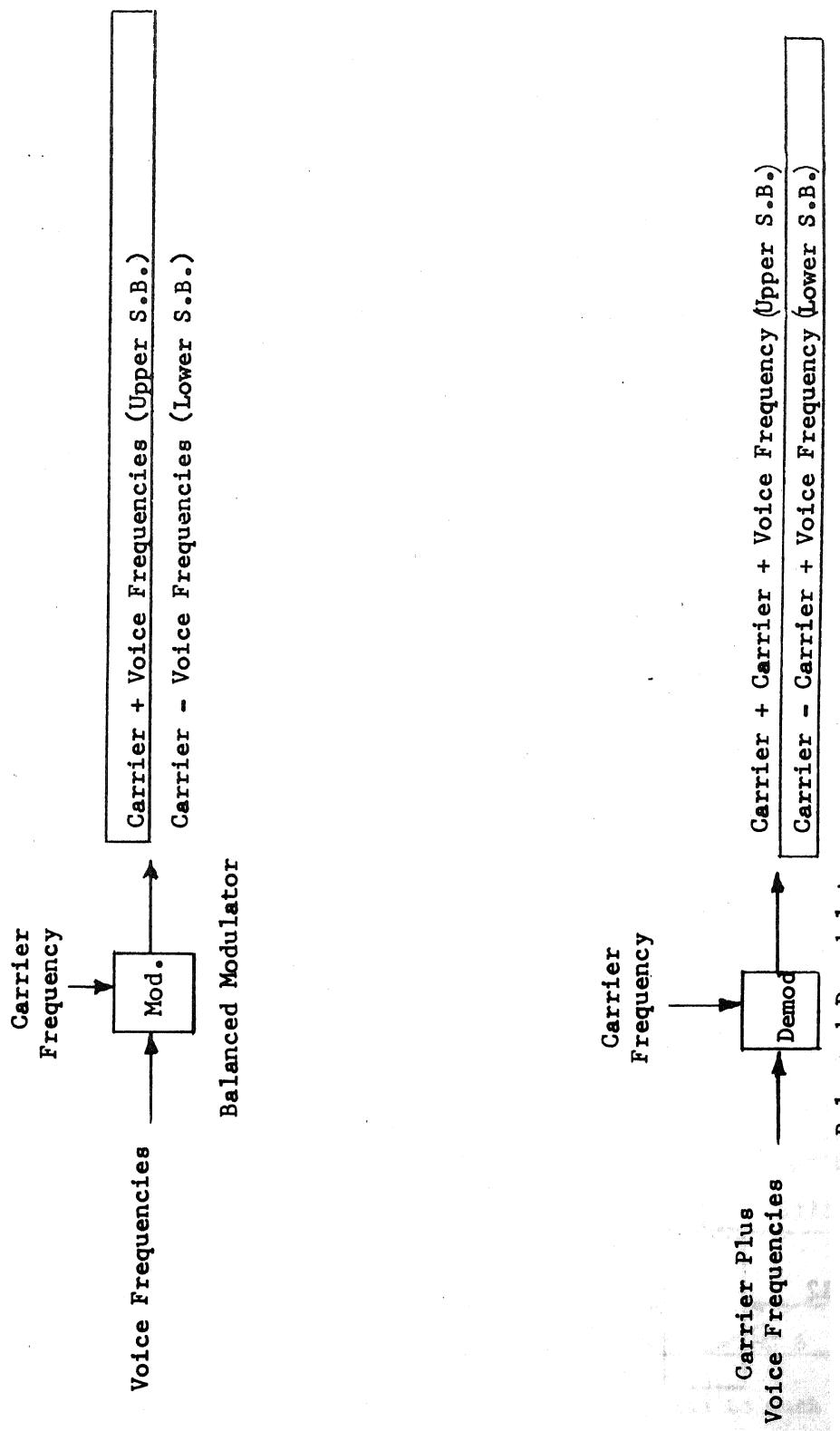
REA TE&CM 934

4.12 Floor plans for FDM multiplex systems deserve special attention
      during the applications phase of system design. The cost of
moving equipment racks, expanding buildings and retiring equipment that
cannot be reused is substantial. One serious hindrance to floor space
planning is the difficulty of appreciating how many racks of equipment
are required for a full 600 channel FDM multiplex system. Twenty plus
racks of equipment for 600 channels is not uncommon! Compare this floor
space requirement to a set of plans and specifications which requires a
potential growth of 600 channels and contains floor plans showing only
three rack spaces available for multiplex equipment. An impasse will
surely occur. The most important consideration is to provide a plan
which can grow. It is surely wrong to place a signaling equipment rack
adjacent to the first few multiplex racks in a new system. One of the
best guides to multiplex floor planning is to dedicate one line of equip-
ment to radio and cable terminating racks. The next row should be dedi-
cated to multiplex, perhaps the next two rows. Another row should be
dedicated to terminating equipment and another to signaling equipment
where inband signaling is to be used. Figure 12 illustrates a desirable
floor plan incorporating this guide. It is not intended for cable
carrier systems. It may appear illogical to dedicate a complete row to
RF and/or coaxial (or video) cable terminals. However, it must be
remembered that high density radio routes add RF channels in the same
way that high density multiplex systems add supergroups. In both RF and
multiplex systems the initial rack installations should be considered as
the first phase of a high density trunking system regardless of known
traffic requirements. The initial cost of this kind of planning results
in slightly higher building costs which are traded for saving when the
first expansion is completed.

4.13 Updating existing systems is expensive because it usually involves
      reallocation of the baseband and relocation of equipment. It
usually occurs when new trunks are needed and it is simultaneously
recognized that these trunks cannot be added unless the system is updated.
Therefore, updating is always complicated by the necessity to add more
trunking capacity. Updating quite often implies poor initial planning.
If performance, expandability and all needed functions such as regulation,
patching, frequency synchronizing, etc., are considered initially, a
suitable plan for updating is the natural result. Where practical,
existing equipment may be reused in the new system with considerable cost
savings. This is particularly true when plug-in modules are removed from
existing racks and inserted into newly wired shelves in a system designed
for orderly growth.

4.14 Factors which influence the reliability of FDM systems are no
      different than other equipment in a system. While it is true
that equipment reliability is important, it is also true that this is
only one of the important factors. The others are (1) the quality of
application engineering, (2) the operating environment, (3) maintenance
personnel, (4) spares and test equipment, (5) documentation and (6)
maintenance schedules. Most of these factors are under the control of

the application engineer. Personnel and maintenance schedules are not. If the engineer will specify redundant active modules (amplifiers), the system realibility is increased. If spare line facilities are specified and terminated in convenient patching facilities, restoral time can be minimized when working lines fail. An alarm system which senses loss of a pilot tone is a quick way to alert personnel when a failure or level change has occurred. Engineers should aquaint themselves with the environment in which the equipment will work. When equipment performance specifications require controlled temperature, humidity and voltage sources, the engineer should specify environment conditioning equipment to assure that these controls are provided. An application engineer should arrange to provide drawings and maintenance manuals which will be needed to quickly locate a trouble. Spare modules can reduce the time to restore service. Adequate test equipment used by well trained personnel can aid restoration of service and help maintain system operation at peak performance. Application engineers should specify the levels of training needed to maintain the new equipment. Two well trained employees with good maintenance scheduling can maintain a vast amount of equipment provided the application engineer has done his work well. The net-effect will be a reliable system.

Carrier
Frequency

Voice Frequencies

Mod.

Carrier + Voice Frequencies (Upper S.B.)

Carrier - Voice Frequencies (Lower S.B.)

Balanced Modulator

Carrier
Frequency

Carrier Plus
Voice Frequencies

Demod

Carrier + Carrier + Voice Frequency (Upper S.B.)

Carrier - Carrier + Voice Frequency (Lower S.B.)

Balanced Demodulator

MODULATION AND DEMODULATION

FIGURE 1

$$F_1$$

Channel 1 VF $\longrightarrow$ Mod.

$$F_2$$

Channel 2 VF $\longrightarrow$ Mod.

Coaxial or Microwave
Radio Line

$$F_1 + VF_1$$
$$F_2 + VF_2$$
$$F_3 + VF_3$$

$$F_n$$

Channel n VF $\longrightarrow$ Mod.

ILLUSTRATION OF LOW DENSITY
MULTIPLEX MODULATION
PLAN

FIGURE 2

Channel
Carriers F_{1-12} Group
Carrier F_1

Channel 1-12 $\longrightarrow$ Mod.

SG
III

Coaxial or Microwave
Radio Line

Super Group
Carrier F_I

SG
II

Group
Carrier F_5

SG
I

Channel 1-12 $\longrightarrow$ Mod.

Mod.

ILLUSTRATION OF HIGH DENSITY
MULTIPLEX MODULATION PLAN

FIGURE 3

.3   3.4 kHz Voice Channel

60 kHz   108 kHz

WE Co and CCITT
Basic Group
(12 Channels)

12 11 10 9 8 7 6 5 4 3 2 1

312 kHz   552 kHz

WE Co and CCITT
Basic Supergroup
(60 Channels)

1 2 3 4 5 Groups

Highest Frequency
Lowest Frequency

60 kHz   4028 kHz

CCITT
16 Supergroups
(960 Channels)

1 2 3 4 5 6 7 8 9 10 11 Supergroups

60 kHz   2788 kHz

Western Elec.
L1
(600 Channels)

1 2 3 4 5 6 7 8 9L 10L Supergroups

564 kHz   3084 kHz

Western Electric
L4 (U600)
Basic Mastergroup
(600 Channels)

3 4 5 6 7 8 9M 10M 11M 12M Supergroups

60 kHz   8372 kHz

Western Union
(1800 Channels)

MG 1   MG 3   MG 4   MG 5   MG 6 Mastergroups
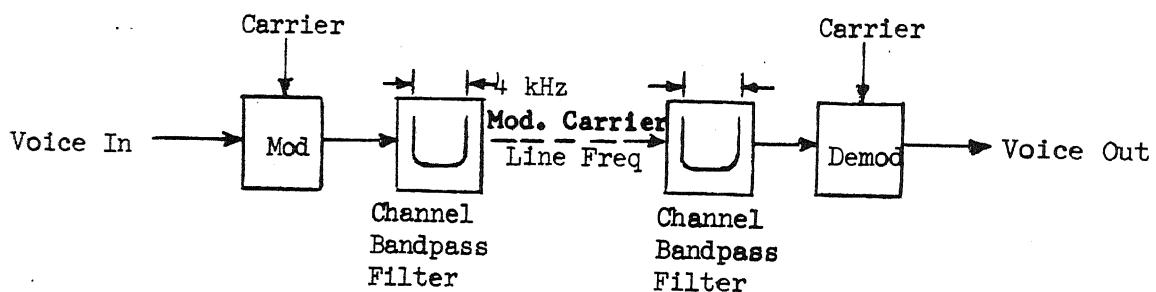
Note 1: Western Electric and CCITT plans progress to much higher
         frequencies than shown.
Note 2: Group, Supergroup, Mastergroup and Line Pilot frequencies
         not shown.

Carrier

Voice In → [Mod] → [Channel Bandpass Filter] → **Mod. Carrier** / Line Freq → [Channel Bandpass Filter] → [Demod] → Voice Out

|←4 kHz

Carrier

MODULATION AND DEMODULATION
WITH CHANNEL FILTERS

FIGURE 5

Signaling Filter / 3.4 kHz

Carrier

Channel Filter

Channel Filter

Carrier

Signaling Filter / 3.4 kHz

Voice In → [ ] → [Mod] → [Channel Filter] – – – → [Channel Filter] → [Demod] → [ ] → Voice Out

Signaling In → [SW]

3.8 kHz

[Det] → Signaling Out
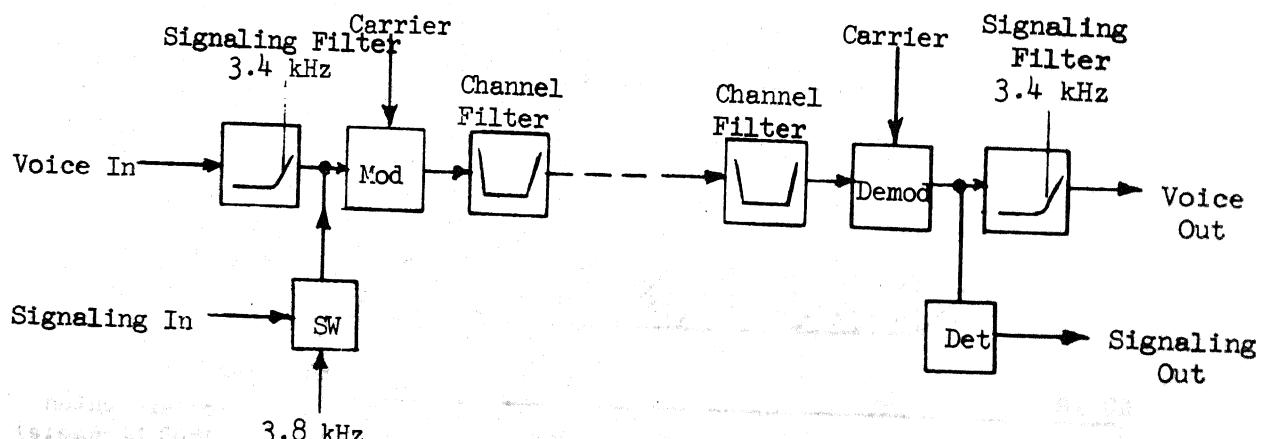
MODEM WITH CHANNEL FILTERS,
SIGNALING FILTERS AND SIGNALING ADDED
(OUT OF BAND SIGNALING)

FIGURE 6

DIAGRAM OF A HIGH DENSITY FDM MULTIPLEX SYSTEM

FIGURE 7

* Only used in very high density systems

POOR APPLICATION

Originating
Office A

Junction
Station

Terminating
Office C

| SG I | Signal$_A$ + Noise$_A$
No Regulating Pilot

Signals$_{A+B}$ + Noise$_{A+B}$
Regulating Pilot$_B$

SG I

Originating
Office B

SG I | Signal$_B$ + Noise$_B$
Regulating Pilot$_B$

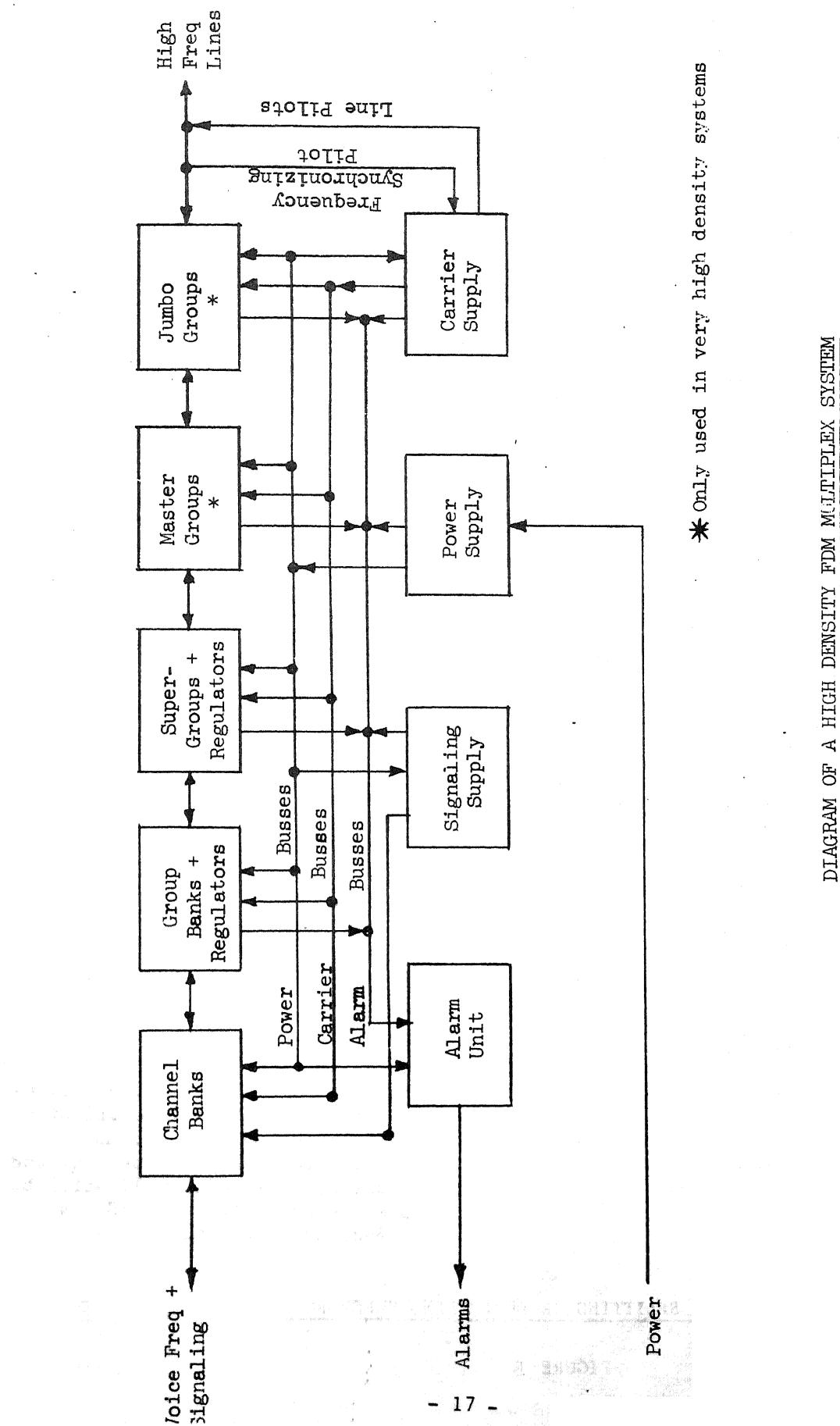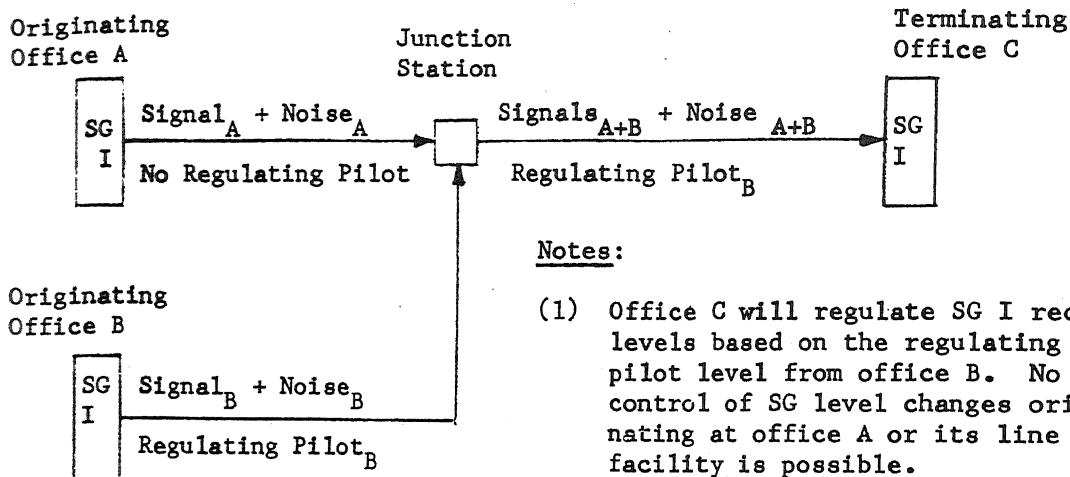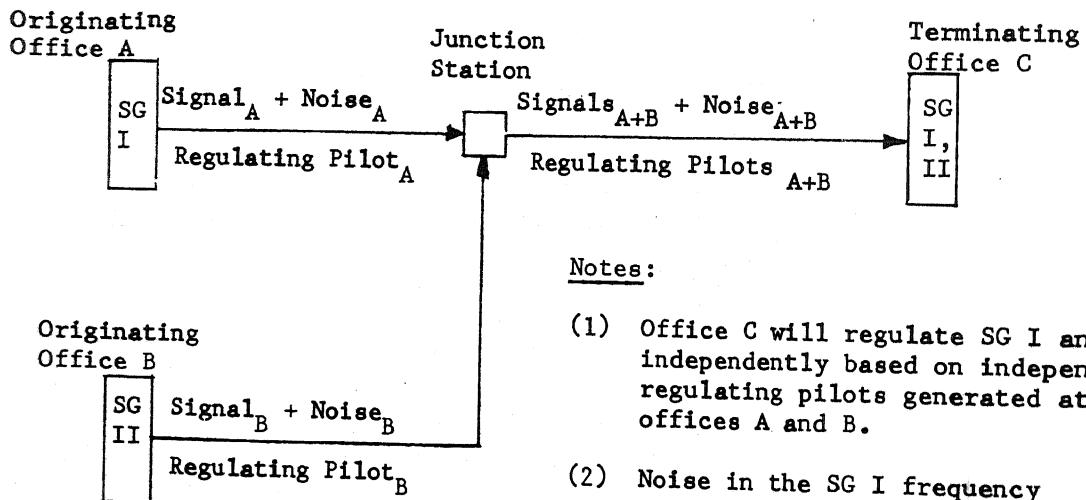Notes:

(1) Office C will regulate SG I receive levels based on the regulating pilot level from office B. No control of SG level changes originating at office A or its line facility is possible.

(2) Noise in the SG I frequency spectrum received at office C will be a summation of office A and B multiplex terminals and all of the baseband noise in the wideband line facilities from offices A and B.

BETTER APPLICATION

Originating
Office A

Junction
Station

Terminating
Office C

SG I | Signal$_A$ + Noise$_A$
Regulating Pilot$_A$

Signals$_{A+B}$ + Noise$_{A+B}$
Regulating Pilots$_{A+B}$

SG I, II

Originating
Office B

SG II | Signal$_B$ + Noise$_B$
Regulating Pilot$_B$

Notes:

(1) Office C will regulate SG I and II independently based on independent regulating pilots generated at offices A and B.

(2) Noise in the SG I frequency spectrum received at office C will be reduced because office B terminal equipment is not contributing SG I noise. Office B common amplifier noise plus its wideband facility line noise will still be present at office C in SG I's frequency spectrum.

EFFECTS OF SPLITTING OR DEDICATING SUPERGROUPS

FIGURE 8

POOR APPLICATION

4 Wire - 3 Way
Baseband Bridge

Office A
Branch

Office C
Branch

Office B
Branch

Notes:
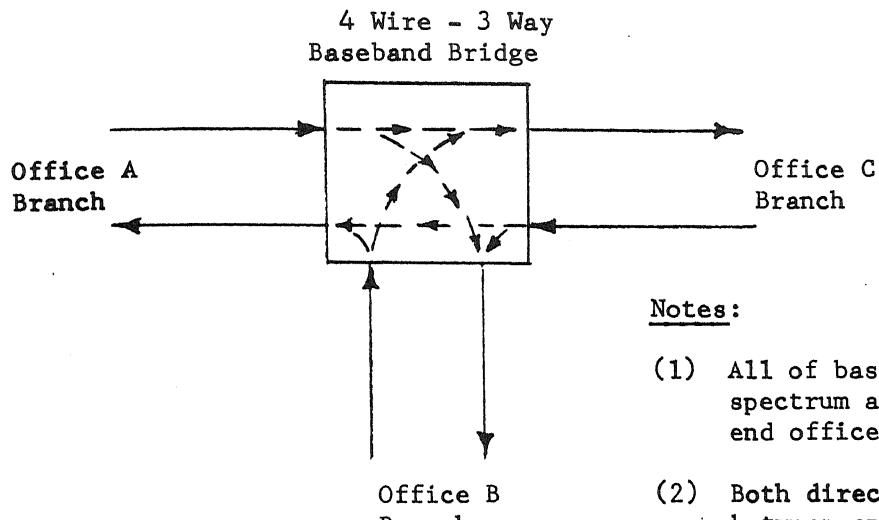
(1) All of baseband frequency
spectrum appears at each
end office.

(2) Both directions of traffic
between any two offices are
received at the third office.

(3) Noise occurring in any branch
is applied to all other
branches.

PREFERRED APPLICATION

Office A
Branch

LP
HP

Office C
Branch

LP
HP

Splitting Fi

Office B
Branch
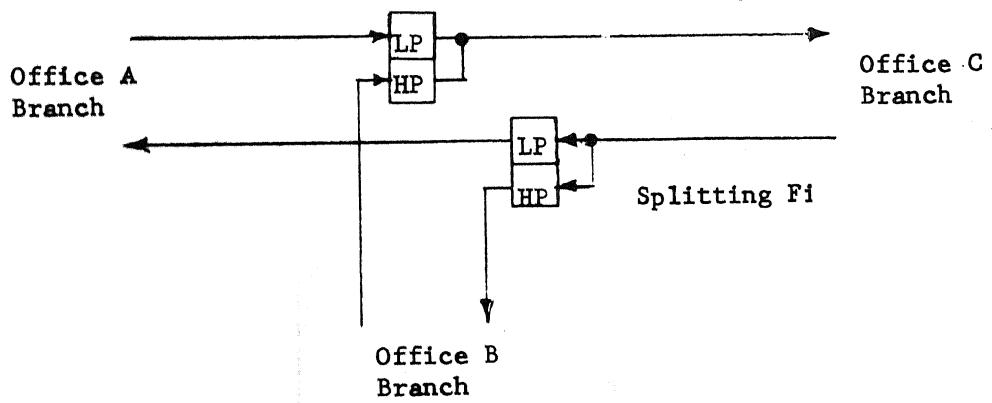
EFFECTS OF BASEBAND BRIDGES AND BASEBA

FIGURE 9

MULTIPLEX INTERCONNECTION DETAILS
AT A
ROUTE JUNCTION

FIGURE 10

NOTE:
1. Only one direction of transmission is shown on this sketch

2. No modulation occurs in a group or supergroup connector

One Hop to
Connecting Co.
Toll Center

Station A

RF

MUX

Grp. Conn.

MUX

RF

Equipment Noise	*PWPO
RF (One Hop)	158
Antenna System (One Hop)	50
Multiplex (VF-VF)	200
SG Connect	20
Grp Connect	40

✳ Information from equipment
manufacturers specifications

Station B

RF

HP LP

MUX

SG X ○

RF

Trunk Group		Equip.	Noise
Station A - T.C.		RF	158
Station C - D		ANT.	50
Station D - E		MUX	200
		Total	408
		→ 26 dBrnc0	
Station B - T.C.		RF	316
Station D-A		ANT.	100
		MUX	200
		G. Conn.	40
		Total	656
		→ 28 dBrnc0	
Station C - T.C.		RF	632
Station E - T.C.		ANT.	200
		MUX	200
		SG Conn.	20
		G. Conn.	40
		Total	1092
		→ 30 dBrnc0	
Station D - T.C.		RF	474
		ANT.	150
		MUX	200
		G. Conn.	40
		Total	864
		→ 29 dBrnc0	
Station C - E		RF	316

RF

MUX

Station C

Station D

MUX RF

RF MUX

SG I

SG V

SG III

SG VIII

SG V

SG X

MUX RF

SG Conn.

NOISE TRUNK GROUP APPROXIMATIONS

Building

RF and/or Cable Terms.

MUX

MUX

VF Term. Sets

Signaling (SF)

Misc.

IDF

Direction of
Future Growth
⟶

Other Types of C.O. Equip.
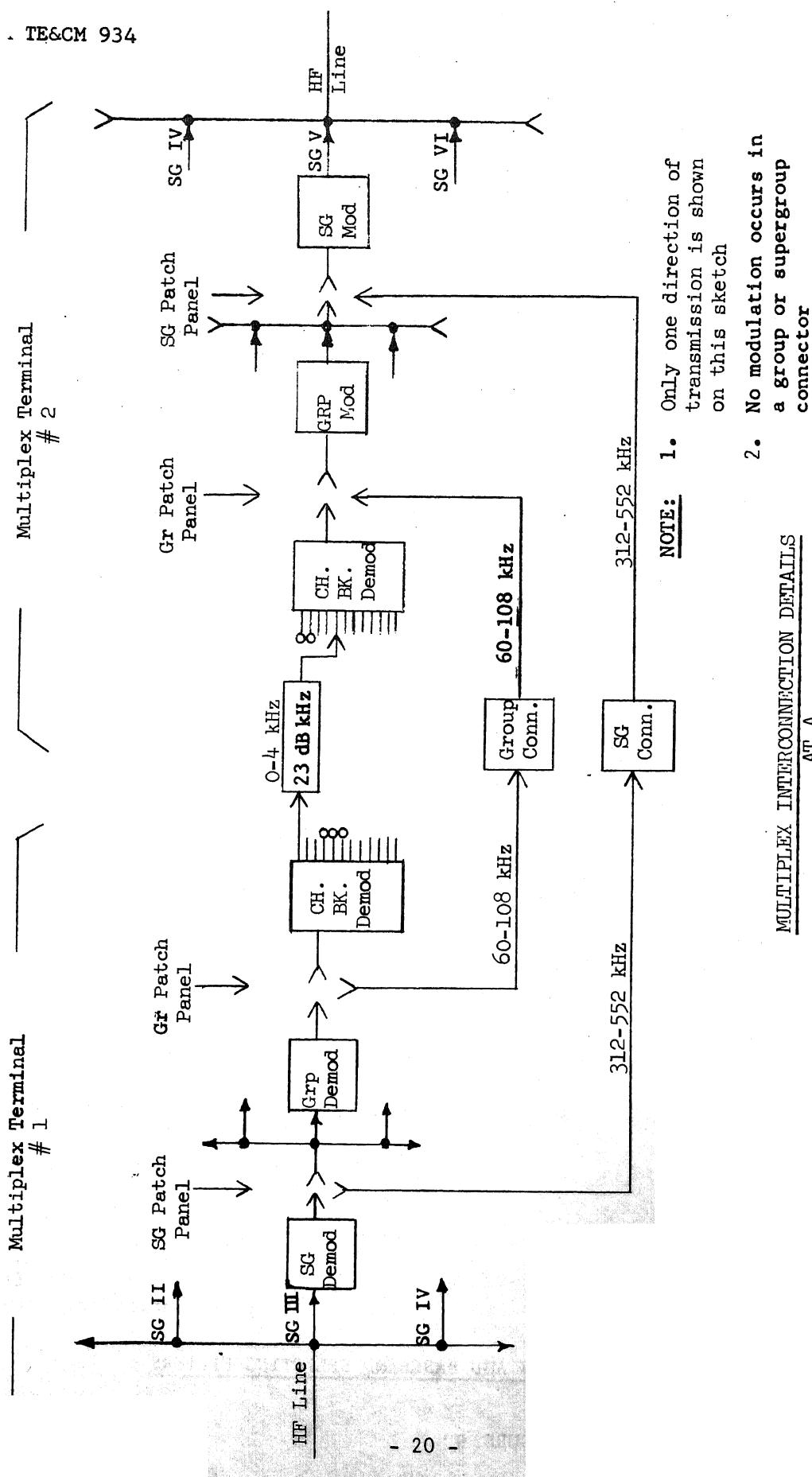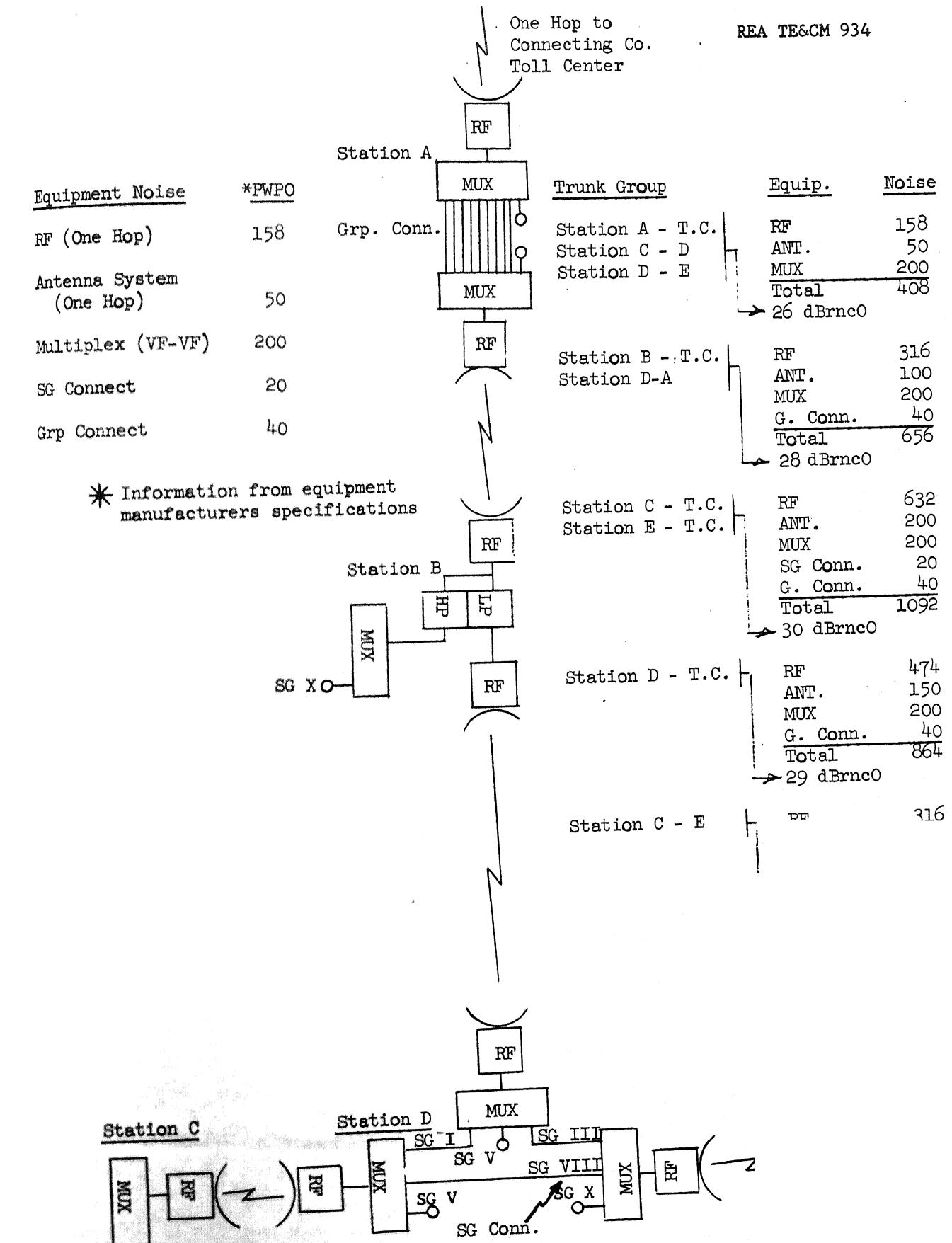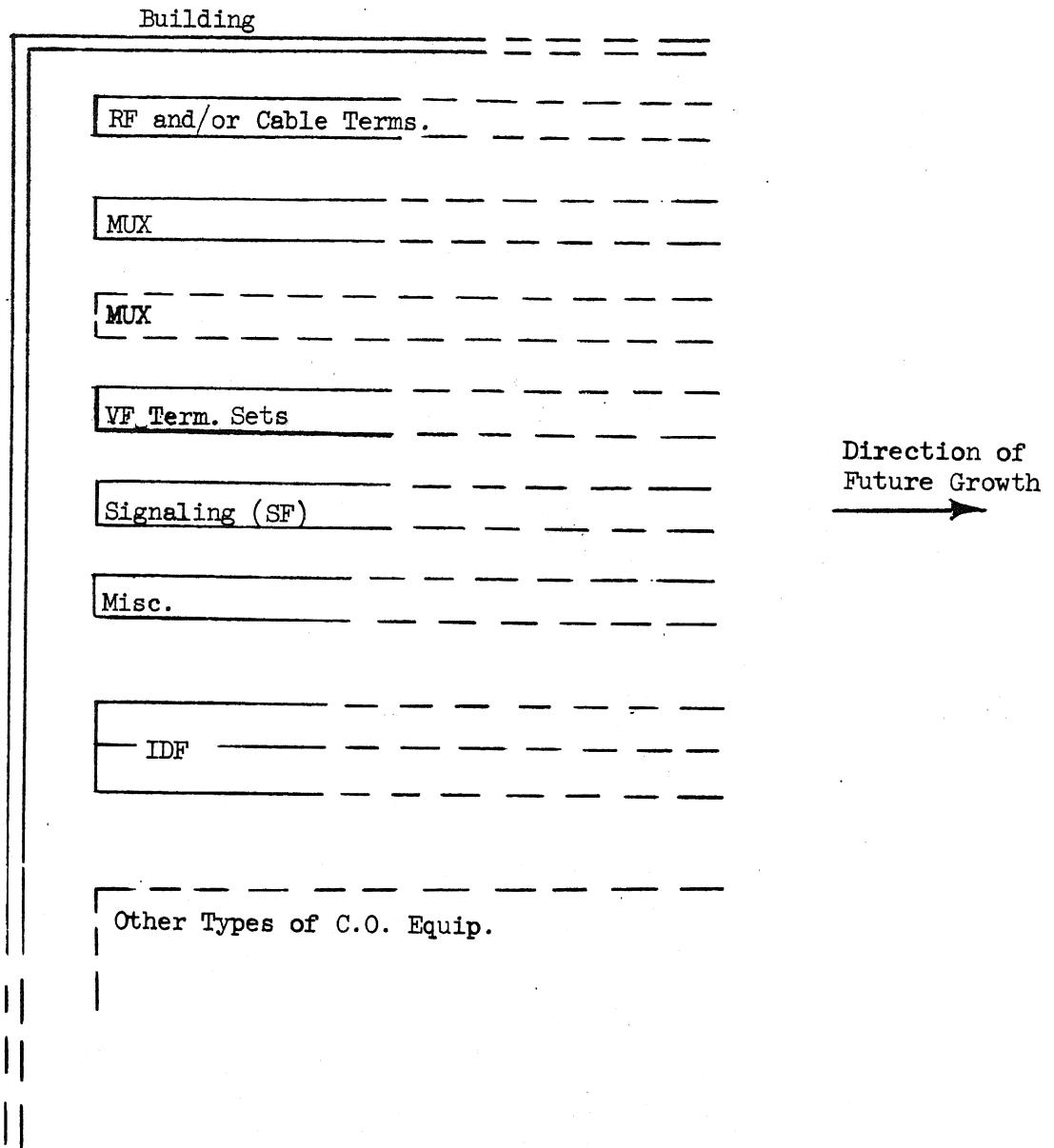
HIGH DENSITY
FDM MULTIPLEX FLOOR SPACE PLAN

FIGURE 12